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RESEARCH MEMORANDUM

for the

Bureau of Aeronautics, Department of the Navy

FREE-SPINNING-TUNNEL INVESTIGATION OF A 1/20-SCALE MODEL OF THE DOUGLAS A4D-1 AIRPLANE

TED NO. NACA DE 389

By Walter J. Klinar, Stanley H. Scher,
and Frederick M. Healy

Langley Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
WASHINGTON

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SUMMARY

Spin and recovery characteristics have been determined for a 1/20-scale dynamic model of the Douglas A4D-1 attack airplane by means of tests in the Langley 20-foot free-spinning tunnel. Erect spins and recoveries were investigated with the model in the clean condition and for loading conditions which include a center external store with and without two external wing fuel tanks installed. The effects of changing horizontal-tail incidence, opening dive brakes, extending slats, or moving the center of gravity forward 10 percent of the mean aerodynamic chord were also determined. The inverted spin and recovery characteristics were investigated and tests were included to determine the size of spin-recovery tail parachute which would provide satisfactory spin recovery in the event of an emergency during spin-demonstration flights.

The model tests showed that the control manipulation most conducive to recoveries from spins will be simultaneous full rudder reversal to full against the spin and aileron movement to full with the spin (stick full right in a right erect spin). However, aileron movement to full with the spin should not be required for all loading conditions of the airplane, and, therefore, for some conditions it is desirable not to move the ailerons with the spin to avoid any possibility of entering a roll after spin termination. The results of the model tests indicate that for the loading conditions of the Douglas A4D-1 airplane with external stores not installed, satisfactory recoveries should be obtained by aileron neutralization and rudder reversal to full against the spin followed shortly thereafter by forward movement of the stick. If deliberate

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spins must be entered with the external stores installed, the horizontal-tail incidence should be set at 12° leading edge down, the slats should be locked in the extended position, if possible, and recovery should be attempted by reversing the rudder to full against the spin and simultaneously moving the ailerons to full with the spin. Aileron-against settings should be avoided, inasmuch as they will have an adverse effect on recoveries. Opening dive brakes should have no appreciable effects on spins and recoveries. Recoveries from inverted spins should be accomplished satisfactorily by neutralization of all controls. A 7.5-foot-diameter (laid-out-flat) flat-type tail parachute with a drag coefficient of 0.7 attached to a 30-foot towline should be adequate as an emergency spin-recovery device.

INTRODUCTION

At the request of the Bureau of Aeronautics, Department of the Navy, an investigation has been made of a 1/20-scale model of the Douglas A4D-1 airplane in the Langley 20-foot free-spinning tunnel. The A4D-1 airplane is a jet-propelled, low swept-wing, single-seat attack airplane.

Erect- and inverted-spin and recovery characteristics of the A4D-1 model in the clean condition were determined for the normal gross-weight loading with the center external store removed and with the horizontal tail set at 4° leading edge up. For this loading condition, the effects on erect spins and recoveries of extending dive brakes, extending slats, or moving the center of gravity forward 10 percent of the mean aerodynamic chord were determined. In addition, the effects on erect spins and recoveries of adding the 1,050-pound center store below the fuselage and the effects of adding the center store plus fuel tanks below the wing were studied for both the slat-retracted and slat-extended conditions. The effects of setting the horizontal tail at 12° leading edge down were investigated for the loading with the center external store installed. The size of spin-recovery tail parachute necessary to insure satisfactory spin recovery during an emergency in spin-demonstration flights of the airplane was also determined.

An appendix is included which presents a general description of the model testing technique, the precision with which model test results and mass characteristics are determined, variations of model mass characteristics occurring during the tests, and a general comparison between model and airplane results.

SYMBOLS

b	wing span, ft
$\bar{c}$	mean aerodynamic chord, ft
$x/\bar{c}$	ratio of distance of center of gravity rearward of leading edge of mean aerodynamic chord to mean aerodynamic chord
$z/\bar{c}$	ratio of distance between center of gravity and fuselage reference line to mean aerodynamic chord (positive when center of gravity is below line)
m	mass of airplane, slugs
I_X,I_Y,I_Z	moments of inertia about X, Y, and Z body axes, respectively, slug-ft^2
$\frac{I_X - I_Y}{mb^2}$	inertia yawing-moment parameter
$\frac{I_Y - I_Z}{mb^2}$	inertia rolling-moment parameter
$\frac{I_Z - I_X}{mb^2}$	inertia pitching-moment parameter
ρ	air density, slugs/cu ft
μ	relative density of airplane, $m/\rho Sb$
α	angle between fuselage reference line and vertical (approximately equal to absolute value of angle of attack at plane of symmetry), deg
ϕ	angle between span axis and horizontal, deg
V	full-scale true rate of descent, ft/sec
Ω	full-scale angular velocity about spin axis, rps

[redacted]

MODEL

The 1/20-scale model of the Douglas A4D-1 airplane was furnished by the Bureau of Aeronautics, Department of the Navy, and was prepared for testing by the Langley Aeronautical Laboratory of the National Advisory Committee for Aeronautics. A three-view drawing of the model as tested is shown in figure 1.

The size, shape, and position of the center external store as tested on the model are shown in figure 2, and the size, shape, and positions of the external fuel tanks are shown in figure 3. Inasmuch as the exact dimensions of the center store were not available, the shape was arrived at on the basis of the mass data and of a sketch shown on a general-arrangement drawing of the airplane. It is felt that the store used is fairly close to the actual store shape. The dimensional characteristics of the airplane are presented in table I. Photographs of the model are shown in figures 4 and 5.

The model was ballasted to obtain dynamic similarity to the airplane at an altitude of 15,000 feet (ρ = 0.001496 slug/cu ft). A remote-control mechanism was installed in the model to actuate the controls for the recovery attempts. Sufficient torque was exerted on the controls for the recovery attempts to reverse them fully and rapidly.

The normal maximum control deflections used on the model during the test (measured perpendicular to the hinge lines) were:

Rudder, deg	25 right, 25 left
Elevator, deg (with respect to horizontal tail) . .	25 up, 15 down
Ailerons, deg	20 up, 20 down

The extremes in horizontal tail incidence used on the model were 4° leading edge up and 12° leading edge down. All tests were made with slats retracted, except as indicated.

RESULTS AND DISCUSSION

The results of the model tests are presented in charts 1 to 8 and in table II. Spins to the pilot's right and left were similar, and the data are arbitrarily presented in terms of right spins. Model loading conditions investigated, as indicated on the charts and in table II, are listed in table III along with airplane loading conditions.

Erect Spins; No External Stores; Horizontal-Tail

Incidence, 4° Leading Edge Up

Clean condition.- Chart 1 presents the results of erect-spin and recovery tests made with the model in the clean condition at the normal gross-weight loading with the center external store not installed (loading 1 in table III). The aileron-neutral spins were steep with a whipping motion, the aileron-against spins were oscillatory primarily in roll and yaw, and the aileron-with spins were very steep. In addition to the spin, a no-spin condition was also obtained for most of the control settings tested. The model recovered rapidly by rudder reversal from all spins obtained. The results indicate that for this loading the recovery characteristics of the airplane by use of the normal control manipulation for recovery (full rudder reversal followed approximately one-half turn later by forward movement of the stick) should be satisfactory.

Dive brakes or slats extended.- Erect-spin and recovery test results obtained with dive brakes extended or with slats extended are presented in charts 2 and 3, respectively. These tests were conducted for the normal gross-weight loading with center external store removed (loading 1 in table III). The results show no appreciable differences from the results obtained for the clean condition.

Mass variations.- The results of the tests of the model with the center of gravity moved forward 10 percent of the mean aerodynamic chord from normal (loading 2 in table III) are presented in chart 4. Comparison of the data presented in chart 4 with that presented in chart 1 indicates that moving the center of gravity forward had a somewhat adverse effect. This is evidenced by the lack of no-spin conditions with the center of gravity moved forward (chart 4) and also by the fact that forward movement of the center of gravity caused poorer recoveries by rudder reversal alone from the aileron-full-against spins. When the ailerons were moved from full against to full with the spin as the rudder was reversed, however, recoveries from the aileron-against spins were rapid, the ensuing motion after termination of the spin being an aileron roll. Although not specifically tested for this loading, analysis indicates that movement of the ailerons to only neutral in conjunction with rudder reversal and subsequent forward movement of the stick should lead to satisfactory recoveries from spins entered by the airplane with the ailerons full against the spin and the stick at or near full back. This analysis is based on the rapidity of the recoveries obtained when ailerons were moved to full with the spin in conjunction with rudder reversal and on results of subsequent tests conducted for another loading condition, in which ailerons were neutralized in conjunction with rudder reversal. It should be pointed out that the indicated adverse effect of moving the center of gravity forward on recovery by rudder reversal alone has also been noted on other models with sweptback or delta wings and with mass arrangements in which the weight is heavily distributed along the fuselage as it is on the Douglas A4D-1 airplane.

Although no tests were conducted on the model for the other loading conditions tabulated in table III as being possible on the airplane with no external stores installed, analysis indicates that the spin-recovery characteristics of the airplane for these conditions should be similar to those for the conditions investigated on the model. That is, for loadings in which the center of gravity is near the quarter-chord point, recovery should generally be satisfactory by rudder reversal followed shortly thereafter by forward movement of the stick. For forward positions of the center of gravity, however, if spins are entered with ailerons at or near full against the spin, aileron movement to at least neutral in addition to rudder reversal will be required for recovery.

Erect Spins; Stores Installed

Normal gross weight; horizontal-tail incidence, 4° leading edge up.- The results of tests made on the model for the normal gross-weight loading which includes the 1,050-pound center external store (loading 5 in table III) with slats retracted and extended and with the horizontal-tail incidence set at 4° leading edge up are shown in chart 5. Installation of the center external store had an adverse effect on the model spin-recovery characteristics. With slats retracted, the recovery characteristics by rudder reversal alone were considered unsatisfactory on the basis of the poor recoveries obtained from the criterion spin (elevator full up and ailerons one-third against the spin, and for recovery, either rudder or ailerons and rudder moved almost their full travel; as is indicated in the appendix, if recovery requires more than $2\frac{1}{4}$ turns for this control setting and control manipulation, the recovery characteristics of the airplane are considered unsatisfactory). The recovery characteristics were improved considerably when simultaneous rudder reversal and aileron movement to with the spin were employed, but the recoveries were not considered satisfactory because slow recovery was still possible from the criterion spin. When the slats were extended, the recoveries obtained by simultaneous rudder and aileron movement were satisfactory, and although recoveries were not attempted for this condition by rudder reversal alone, analysis based on subsequent tests for another loading indicates that rudder reversal alone would have been ineffective. It should be noted that for recovery attempts made by movement of ailerons to with the spin in conjunction with rudder reversal, the spin often terminated in an aileron roll. The model results indicate, however, that a roll would be less likely to occur on the airplane if the stick is maintained full back than for neutral or forward stick positions. The beneficial effect on recovery of extending slats for the subject model is in agreement with results given in reference 1, wherein it is shown that such a beneficial effect may be expected for airplanes loaded relatively more heavily along the fuselage than along the wings.

Normal gross weight; horizontal-tail incidence, 12° leading edge down.- The results of tests made on the model for the normal gross-weight loading (loading 5 in table III) with slats retracted and with the horizontal-tail incidence at 12° leading edge down are shown in chart 6. Comparison of charts 5 and 6 indicates that placing 12° leading-edge-down incidence on the horizontal tail had a favorable effect. In this condition the model was less prone to spin than it was with the horizontal-tail incidence at 4° leading edge up; that is, the model would not then spin when the ailerons were either neutral or with the spin. In addition, recoveries from the aileron-against spins by aileron movement and rudder reversal were improved. This is particularly apparent for the criterion spin, where neutralization of ailerons in conjunction with rudder reversal leads to satisfactory recoveries. On the full-scale airplane it would appear desirable to move ailerons to full with the spin to insure recovery. To avoid recovering into an aileron roll it is advisable to keep the stick full back until the rotation ceases. On the basis of these tests it is apparent that the best incidence of the horizontal tail for spins on the full-scale airplane is 12° leading edge down.

Alternate gross weight, long range.- The results of tests made on the model for a loading closely simulating the alternate gross-weight, long-range loading which includes the center external store plus two full external fuel tanks (loading 6 in table III) and with the horizontal-tail incidence set at 4° leading edge up are presented in chart 7. The data are presented both for the slat-retracted and the slat-extended conditions. The results indicate that the spin and recovery characteristics of the model for this loading were not appreciably different from those obtained when the center store alone was installed.

Other loading conditions.- Results of brief tests and analysis indicate that, for the other loading conditions presented in table III which are possible on the airplane when the 1,050-pound center external store is installed, satisfactory recoveries should be obtained if the horizontal-tail incidence is first set at 12° leading edge down, the slats are extended, and the following control manipulation is utilized: movement of ailerons to full with the spin in conjunction with full rudder reversal. If the larger external center stores are of approximately the same size and shape as the 1,050-pound center store investigated on the model, the above recovery procedure should also be satisfactory for the loadings listed in table III which include the larger external center stores.

Landing Condition

Current military specifications require airplanes to be spin-demonstrated in the landing condition from only a one-turn (or incipient) spin, and inasmuch as spin-tunnel test data are obtained for fully developed spins, the landing condition was not investigated on the model. Recovery characteristics in the landing condition may be of significant importance, however, because stall tests of airplane, generally made at an altitude in the landing condition early during the flight-test program, may result in an inadvertent spin. Analysis indicates that, although recoveries from fully developed spins may be unsatisfactory (based on the study presented in ref. 2 of the results of tests of many models with landing gear and flaps extended and retracted), the Douglas A4D-1 airplane should recover satisfactorily from an incipient spin in the landing condition. Therefore, if a spin is inadvertently entered in the landing condition at any time, the flaps and landing gear should be retracted and recovery attempted immediately.

Inverted Spins

The results of the inverted-spin and recovery tests of the model in the clean condition are presented in chart 8. The order used for presenting the data for the inverted spins is different from that used for erect spins. For inverted spins, "controls crossed" for the established spin (right rudder pedal forward and stick to the left of the pilot for a spin to the right of the pilot) is presented to the right of the chart and "stick back" is presented at the bottom. When the controls are crossed in the established spin, the lateral controls aid the rolling motion; when the controls are together, the lateral controls oppose the rolling motion. The angle ϕ and the elevator position in the chart are given as up or down relative to the ground.

Results of the inverted spin tests for the normal loading condition with center store removed (loading 1 in table III) presented in chart 8 and results of some brief inverted-spin tests with the model in the normal loading condition with the 1,050-pound center external store installed (loading 5 in table III) which are not presented in chart form indicate that either full rudder reversal or neutralization of all controls should lead to satisfactory recoveries from inverted spins. To avoid pilot confusion, it is recommended that the latter recovery technique be employed.

Spin-Recovery Parachute Tests

The results of tests made to determine the size of tail parachute which would give satisfactory recovery if opened during an emergency while the Douglas A4D-1 airplane is being spin-demonstrated are presented in table II. These tests were conducted for the normal loading condition with the center store removed (loading 1 in table III) and with the rudder held with the spin. The results indicate that a 7.5-foot-diamter (laid-out-flat) flat-type parachute with a drag coefficient of 0.7 and a towline 30 feet long should be adequate. Some other type of tail parachute giving equivalent drag could also be used for satisfactory recovery. Results of an investigation in which both stable and unstable parachutes were used for spin recovery are presented in reference 3.

Recommended Recovery Technique and Control Forces

The ailerons and rudder will be the most effective controls in producing recovery from spins, and the positions of these controls which lead to most rapid termination of the spins are ailerons full with the spin (stick full right in a right erect spin) and rudder full against the spin. Aileron movement to full with the spin should not be required for all loading conditions on the airplane, however, and where not necessary it is desirable not to move the ailerons to with the spin to avoid any possibility of entering an aileron roll after termination of the spin. On this basis, the recovery procedures recommended for the various airplane conditions are as follows:

For erect spins entered with no external stores installed on the airplane, normal control movement should be employed for recovery; that is, the ailerons should be maintained at or moved laterally to neutral, the rudder should be moved to full against the spin, and approximately one-half turn later the stick should be moved forward. Care should, of course, be exercised not to enter a spin in the opposite direction and therefore the rudder should be neutralized as the rotation ceases.

With external stores installed on the airplane, deliberate spins should be avoided. If erect spins must be deliberately entered with the center external store or external wing fuel tanks or a combination of the two installed, the slats should be locked in the extended position, if possible, and the horizontal-tail incidence should be set at 12° leading edge down prior to entry into the spin. Control manipulation for recovery should be as follows: fully reverse the rudder against the spin and simultaneously move the ailerons to full with the spin. When the spinning rotation stops and the airplane begins to glide or begins to roll with the ailerons, neutralize the stick laterally and move it forward longitudinally to regain normal flight. During the recovery procedure it is advisable to keep the stick full back until it is obvious that the airplane is out of the spin, inasmuch as the airplane should be less inclined to roll with the ailerons after termination of the spin for rearward positions of the stick than for longitudinally neutral or forward stick positions. If after applying the recovery procedures recommended previously the airplane shows no indications of recovering from the spin, the external stores should be jettisoned and recovery should be reattempted. If a spin is entered inadvertently with external stores installed, immediate remedial control movement as indicated previously should be applied to prevent the attainment of a developed spin.

If a spin is inadvertently entered while the flaps or landing gear are extended, they should be retracted and recovery attempted immediately.

For recovery from inverted spins, all controls should be neutralized.

No consideration has been given to the forces that would be required to move the controls for recovery. To assure satisfactory recoveries from spins, provision should be made to insure that the pilot can move the controls fully and rapidly.

CONCLUSIONS

Based on the results of tests of a 1/20-scale model of the Douglas A4D-1 airplane in the free-spinning tunnel, the following conclusions regarding the spin and recovery characteristics of the airplane at an altitude of 15,000 feet are made:

1. The control movement most conducive to recoveries will be simultaneous full rudder reversal against the spin and aileron movement to full with the spin (stick full right in a right erect spin). Aileron movement to full with the spin should not be required for spin recovery for all conditions of the airplane, however, and therefore for some conditions it is desirable to neutralize the ailerons rather than to move them to with the spin in order to avoid any possibility of entering a roll after spin termination. The conclusions that follow indicate the recommended control manipulation for the various airplane conditions.

2. For the normal gross-weight loading without center external store and with slats extended or retracted, either the airplane will spin in a steep whipping fashion when the ailerons are at neutral, or the airplane will not spin. Satisfactory recoveries should be achieved from any spins obtained by using normal spin-recovery control manipulation: maintain the stick at or move it laterally to neutral, move the rudder briskly to full against the rotation, and approximately one-half turn later move the stick forward. This control manipulation should also lead to satisfactory recoveries for other loading variations when no external stores are installed on the airplane.

3. Intentional spinning of the airplane with external stores attached should be avoided. If the airplane must be spun deliberately with the center external store or wing fuel tanks or a combination of the two

installed, the slats should be locked in the extended position, if possible, and the horizontal-tail incidence should be set at 12° leading edge down prior to entry into the spin. Recovery should be attempted by simultaneous movement of the rudder to full against the spin and of the ailerons to full with the spin with the stick maintained full back. If recovery does not appear imminent after a few turns, the external stores should be jettisoned and recovery reattempted.

4. For recovery from erect spins the most favorable slat position will be fully extended, and the most favorable horizontal-tail incidence will be 12° leading edge down.

5. Extending the dive brakes should have little effect on spins and recoveries.

6. Neutralizing all controls should lead to satisfactory recoveries from inverted spins.

7. A 7.5-foot diameter (laid-out-flat) spin-recovery tail parachute with a drag coefficient of 0.7 and attached with a 30-foot towline will be adequate to provide satisfactory spin recovery if an emergency arises during spin-demonstration flights.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., December 28, 1954.

Walter J Klinar
Walter J. Klinar
Aeronautical Research Scientist

Stanley H. Scher
Stanley H. Scher
Aeronautical Research Scientist

Frederick M. Healy
Frederick M. Healy
Aeronautical Research Scientist

Approved: Thomas A. Harris
Thomas A. Harris
Chief of Stability Research Division

DH

APPENDIX

METHODS AND PRECISION

Model Testing Technique

The operation of the Langley 20-foot free-spinning tunnel is generally similar to that described in reference 4 for the Langley 15-foot free-spinning tunnel except that the model-launching technique is different. With the controls set in the desired position, a model is launched by hand with rotation into the vertically rising air stream. After a number of turns in the established spin, a recovery attempt is made by moving one or more controls by means of a remote-control mechanism. After recovery, the model dives into a safety net. The tests are photographed with a motion-picture camera. The spin data obtained from these tests are then converted into corresponding full-scale values by methods described in reference 4.

Spin-tunnel tests are usually performed to determine the spin and recovery characteristics of a model for the normal spin-control configuration (elevator full up, lateral controls neutral, and rudder full with the spin) and for various other lateral control and elevator combinations including neutral and maximum settings of the surfaces. Recovery is generally attempted by rapid full reversal of the rudder, by rapid full reversal of both rudder and elevator, or by rapid full reversal of the rudder simultaneously with moving ailerons to full with the spin. The particular control manipulation required for recovery is generally dependent on the mass and dimensional characteristics of the model (refs. 5 and 6). Tests are also performed to evaluate the possible adverse effects on recovery of small deviations from the normal spin-control configuration. For these tests, the elevator is set either full up or at two-thirds of its full-up deflection and the lateral controls are set at one-third of full deflection in the direction conducive to slower recoveries, which may be either against the spin (stick left in a right spin) or with the spin, depending primarily on the mass characteristics of the particular model. Recovery is attempted by rapidly reversing the rudder from full with the spin to only two-thirds against the spin, by simultaneous rudder reversal to two-thirds against the spin and movement of the elevator to either neutral or two-thirds down, or by simultaneous rudder reversal to two-thirds against the spin and lateral stick movement to two-thirds with the spin. This control configuration and manipulation is referred to as the criterion spin, with the particular control settings and manipulation used being dependent on the mass and dimensional characteristics of the model.

Turns for recovery are measured from the time the controls are moved to the time the spin rotation ceases and the model enters a dive or a vertical aileron roll. Recovery characteristics of a model are generally considered satisfactory if recovery attempted from the criterion spin in any of the manners previously described is accomplished within $2\frac{1}{4}$ turns. This value has been selected on the basis of full-scale-airplane spin-recovery data that are available for comparison with corresponding model test results.

For spins in which a model has a rate of descent in excess of that which can readily be obtained in the tunnel, the rate of descent is recorded as greater than the velocity at the time the model hit the safety net; for example, >300 feet per second, full scale. In such tests, the recoveries are attempted before the model reaches its final steeper attitude and while it is still descending in the tunnel. Such results are considered conservative; that is, recoveries are generally not as fast as when the model is in the final steeper attitude. For recovery attempts in which a model strikes the safety net while it was still in a spin, the recovery is recorded as greater than the number of turns from the time the controls were moved to the time the model struck the net, as >3. A >3-turn recovery, however, does not necessarily indicate an improvement over a >7-turn recovery. When a model recovers without control movement (rudder held with the spin), the results are recorded as no spin.

For spin-recovery parachute tests, the minimum-size tail parachute required to effect recovery within $2\frac{1}{4}$ turns from the criterion spin is determined. The parachute is opened for the recovery attempts by actuating the remote-control mechanism and the rudder is held with the spin so that recovery is due to the parachute action alone. The parachute towline is generally attached to the bottom rear of the fuselage. The folded spin-recovery parachute is placed on the model in such a position that it does not seriously influence the established spin. A rubber band holds the packed parachute to the model and when released allows the parachute to be blown free of the model. On full-scale parachute installations it is desirable to mount the parachute pack within the airplane structure, if possible, and it is recommended that a mechanism be employed for positive ejection of the parachute.

Precision

Results determined in free-spinning tunnel tests are believed to be true values given by models within the following limits:

α, deg . . . . ±1
ϕ, deg . . . . ±1
V, percent . . . . ±5
Ω, percent . . . . ±2

Turns for recovery obtained from motion-picture records . . . . $\pm\frac{1}{4}$

Turns for recovery obtained visually . . . . $\pm\frac{1}{2}$

The preceding limits may be exceeded for certain spins in which it is difficult to control the model in the tunnel because of the high rate of descent or because of the wandering or oscillatory nature of the spin.

The accuracy of measuring the weight and mass distribution of models is believed to be within the following limits:

Weight, percent	±1
Center-of-gravity location, percent $\bar{c}$	±1
Moments of inertia, percent	±5

Controls are set with an accuracy of ±1°.

Variations in Model Mass Characteristics

Because it is impracticable to ballast models exactly and because of inadvertent damage to models during tests, the measured weight and mass distribution of the A4D-1 model varied from the true scaled-down values within the following limits:

Weight, percent	0 low to 2 high
Center-of-gravity location, percent $\bar{c}$	0
Moments of inertia:	
I_X, percent	0 low to 4 high
I_Y, percent	0 low to 6 high
I_Z, percent	1 low to 3 high

Comparison Between Model and Airplane Results

Comparison between model and full-scale results in reference 7 indicated that model tests accurately predicted full-scale recovery characteristics approximately 90 percent of the time and that, for the remaining 10 percent of the time, the model results were of value in predicting some of the details of the full-scale spins, such as motions in the developed spin and proper recovery techniques. The airplanes generally spun at an angle of attack closer to 45° than did the corresponding models. The comparison presented in reference 7 also indicated that generally the airplanes spun with the inner wing tilted more downward and with a greater altitude loss per revolution than did the corresponding models.

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TABLE I.- DIMENSIONAL CHARACTERISTICS OF
THE DOUGLAS A4D-1 AIRPLANE AS SIMULATED
BY THE 1/20-SCALE MODEL

Overall length, ft	38.44
Wing:	
Span, ft	27.5
Area, sq ft	259.8
Root chord, in.	186
Tip chord (theoretical), in.	42
$\bar{c}$, in.	129.64
Longitudinal distance between leading edge of root chord and leading edge of $\bar{c}$, in.	56.36
Aspect ratio	2.91
Taper ratio	0.23
Sweepback at 0.25-chord line	33°12'24"
Dihedral (at trailing edge), deg	2.67
Incidence, deg	0
Airfoil section:	
Root	NACA 0008-1.1-25-.0875 (.5 × 230)
Tip	NACA 0005-.825-50-.0787 (.5 × 230)
Ailerons:	
Area (both), sq ft	15.97
Span, percent b/2	44.5
Chord, rearward of hinge line, in.	16
Slats:	
Span, percent b/2	54.5
Horizontal tail:	
Span, ft	11.33
Area, sq ft	45.85
Stabilizer area, forward of elevator hinge line, sq ft	34.74
Elevator area, rearward of hinge line, sq ft	11.11
Sweepback at 0.25-chord line	34°21'54"
Root chord, in.	80
Tip chord (theoretical), in.	22
Distance from leading edge of wing at root to leading edge of stabilizer at root, ft	20.29
Dihedral, deg	0
Airfoil section:	
Root	NACA 0007-1.1-25-.07651
Tip	NACA 0004-.825-50-.06291
Vertical tail:	
Span, ft	7.87
Area, sq ft	49.95
Fin area (including rudder balance), sq ft	40.75
Rudder area, rearward of hinge line, sq ft	9.2
Sweepback at 0.25-chord line, deg	42
Root chord, in.	128.25
Tip chord (theoretical), in.	25
Distance from leading edge of wing at root to leading edge of fin at root, ft	16.21
Airfoil section:	
Root	NACA 0007-1.1-25-.08749
Tip	NACA 0004-.825-50-.06291

TABLE II.- SPIN-RECOVERY TAIL-PARACHUTE DATA

OBTAINED WITH THE 1/20-SCALE MODEL OF THE

DOUGLAS A4D-1 AIRPLANE

[Model loading 1 in table III. Recovery attempted by opening tail parachute; right erect spins; horizontal-tail incidence, 4° leading edge up; clean condition. Control setting for spin: elevator full up, ailerons full against, rudder full with spin. Model values have been converted to corresponding full-scale values.]

Parachute diameter, ft	Towline length, ft	Approximate parachute drag coefficient	Turns for Recovery
6.67	30	0.70	>3, >4, >4, >6
7.50	30	.70	$1\frac{1}{4}$, $1\frac{1}{2}$, 2, 2, 2
8.33	30	.71	1, 1, 1, $1\frac{1}{4}$, $1\frac{1}{2}$
9.17	30	.73	$\frac{3}{4}$, 1, 1, $1\frac{1}{4}$, $1\frac{1}{2}$
10.0	30	.71	$\frac{1}{2}$, 1, $1\frac{1}{4}$, $1\frac{1}{2}$, 2
11.67	30	.69	$\frac{1}{2}$, $\frac{3}{4}$, 1, 1, 1
12.5	30	.70	$\frac{3}{4}$, $\frac{3}{4}$, 1, 1, 1

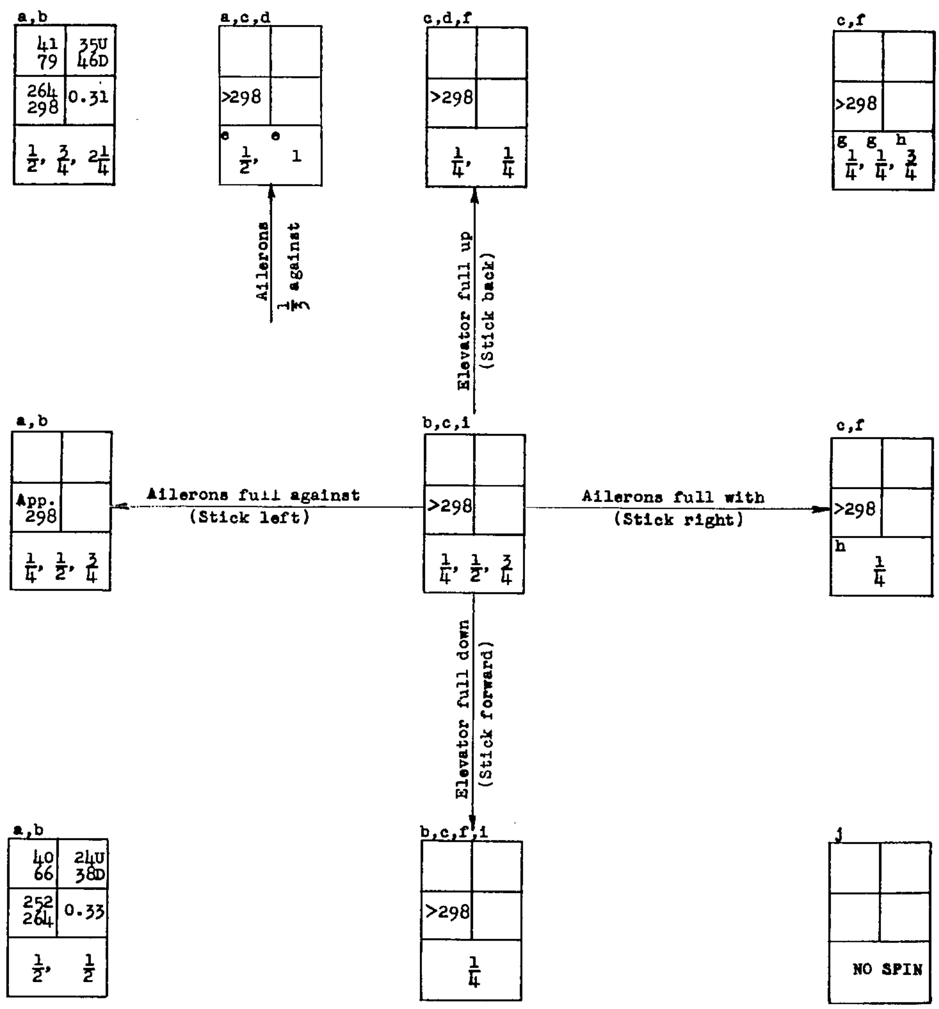
TABLE III.- MASS CHARACTERISTICS AND INERTIA PARAMETERS FOR THE LOADINGS OF THE DOUGLAS A4D-1 AIRPLANE AND FOR LOADINGS TESTED ON THE $\frac{1}{20}$-SCALE MODEL

[Values given are full scale, and moments of inertia are given about the center of gravity; landing gear up; values computed from information presented in refs. 8 and 9.]

No.	Loading		External-store location	Weight (lb)	Center-of-gravity location		Relative density μ		Moments of inertia (slug-feet^2)			Mass	
					$x/\bar{c}$	$z/\bar{c}$	Sea level	15,000 feet	I_X	I_Y	I_Z	$\frac{I_X - I_Y}{mb^2}$	
Airplane values													
1	Normal gross weight with center store removed		None	13,313	0.269	0.110	24.33	38.67	6149	18,100	22,240	-383×10^{-4}	-
2	Loading No. 1 with center of gravity moved forward to 17 percent $\bar{c}$		None	13,313	0.169	0.110	24.33	38.67	6149	18,100	22,240	-383	-
3	Alternate gross weight - fighter		None	13,800	0.256	0.114	25.25	40.13	6217	18,735	22,800	-386	-
4	Extreme balance conditions with external stores removed	Nose heavy	None	10,659	0.167	0.079	19.48	30.96	6075	20,823	25,085	-589	-
		Tail heavy	None	8,910	0.275	0.079	16.30	25.91	6065	18,707	22,924	-603	-
5	Normal gross weight (1050-lb center store on)		Center	14,400	0.259	0.133	26.31	41.81	6551	18,943	22,683	-367	-
6	Alternate gross weight - long range (2 external full fuel wing tanks and 1050-lb center store)		Center	16,420	0.260	0.168	29.98	47.65	9823	19,489	23,354	-251	-
7	Design flight gross weight (1050-lb center store on)	Nose heavy	Center	12,504	0.161	0.094	22.85	36.32	6482	23,455	26,617	-578	-
		Tail heavy	Center	12,504	0.300	0.201	22.85	36.32	7086	23,371	25,929	-554	-
8	Catapult design gross weight (3575-lb center store plus 2 1050-lb wing stores on)	Nose heavy	Center and wing	19,910	0.210	0.197	36.37	57.81	9764	25,760	31,824	-342	-
		Tail heavy	Center and wing	19,910	0.270	0.197	36.37	57.81	9764	26,525	32,589	-359	-
9	Alternate gross weight - overload (3250-lb center store on)		Center	16,600	0.254	0.166	30.37	48.27	6954	20,368	23,721	-344	-
Model values													
1	Normal gross weight with center store removed		None	13,614	0.259	0.104	24.90	39.57	6345	18,832	22,860	-390	-
2	Loading No. 1 with center of gravity moved forward to 17 percent $\bar{c}$		None	13,004	0.170	0.082	23.77	37.77	6387	17,674	21,822	-370	-
5	Normal gross weight (1050-lb center store on)		Center	14,664	0.262	0.128	26.78	42.56	6642	19,778	23,372	-382	-
6	Alternate gross weight - Long range (2 external full fuel wing tanks and 1050-lb center store)		Center	16,615	0.262	0.160	30.37	48.27	9640	22,277	26,185	-324	-

CHART 1.- ERECT SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL IN THE NORMAL GROSS-WEIGHT LOADING WITHOUT CENTER EXTERNAL STORE INSTALLED

[Model loading 1 in table III; horizontal-tail incidence, 4° leading edge up; recovery attempted by rapid full rudder reversal except as indicated (recovery attempted from, and steady-spin data presented for, rudder-full-with spins); spins to pilot's right]



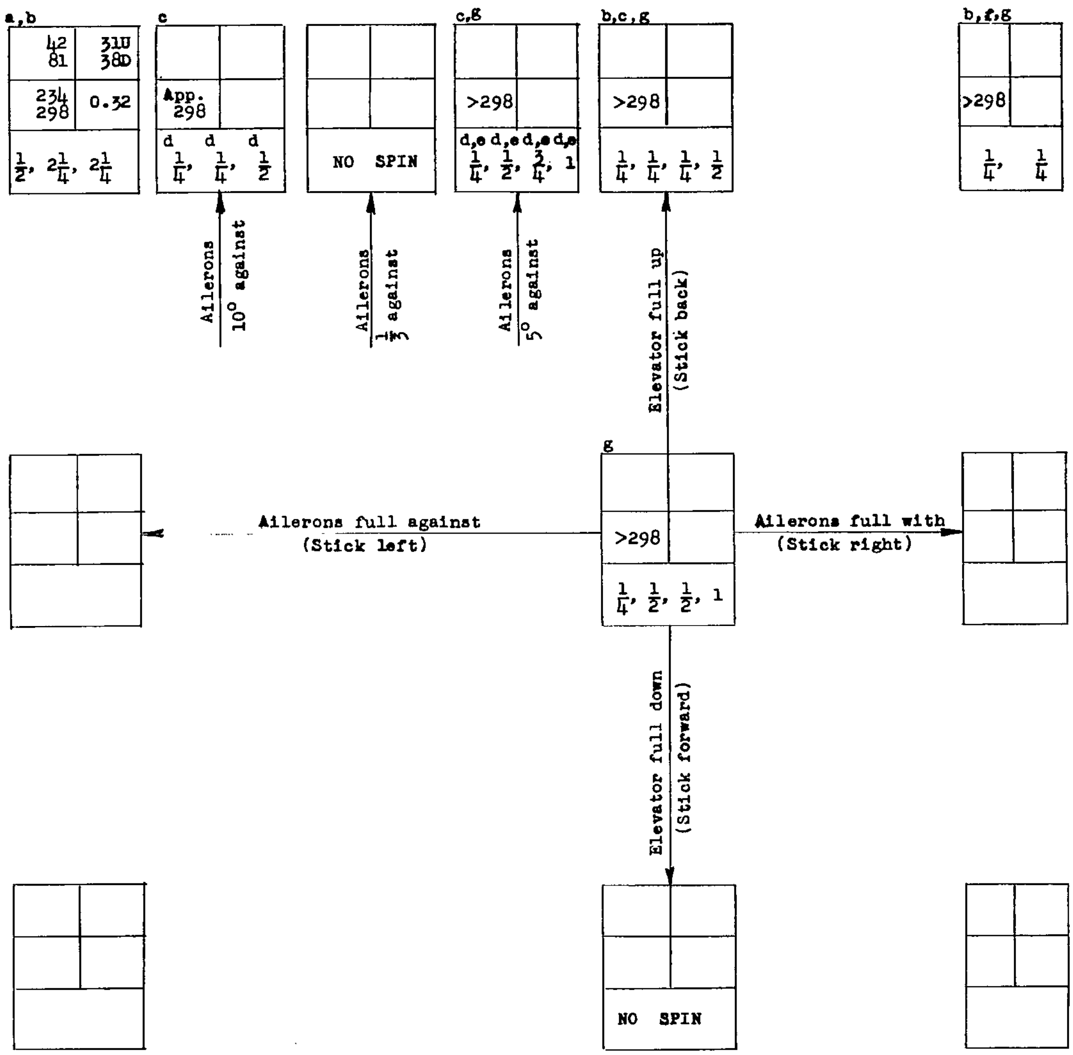
[a]Oscillatory and wandering spin.
[b]No-spin condition also observed; model went inverted.
[c]Steep spin, recovery attempted before final attitude.
[d]No-spin condition also observed; model dived.
[e]Recovery attempted by reversing rudder from full with to $\frac{2}{3}$ against the spin.
[f]Whipping spin.
[g]Recovered in a dive.
[h]Recovered in an aileron roll.
[i]Wandering spin.
[j]Entered an aileron roll.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down
Average or range of values given.

α (deg)	ϕ (deg)
V (fps)	Ω (rps)
Turns for recovery	

CHART 2.- SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL WITH DIVE BRAKES EXTENDED FOR THE NORMAL GROSS-WEIGHT LOADING WITHOUT CENTER EXTERNAL STORE INSTALLED

[Model loading 1 in table III; horizontal-tail incidence, 4° leading edge up; recovery attempted by rapid full rudder reversal, except as indicated (recovery attempted from, and steady-spin data presented for, rudder-full-with spins); erect spins to pilot's right]



[a]Oscillatory and wandering spin.
[b]No-spin condition also obtained.
[c]Whipping and wandering spin.
[d]Recovery attempted by reversing rudder from full with to $\frac{2}{3}$ against the spin.
[e]Recovered in a dive, turning slightly to the left.
[f]Both slow-turning non-oscillatory spin and rapid, whipping spin observed; rapid recoveries from both.
[g]Steep spin, recovery attempted before final attitude.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down
Average or range of values given.

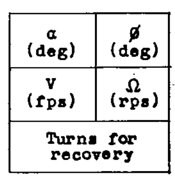
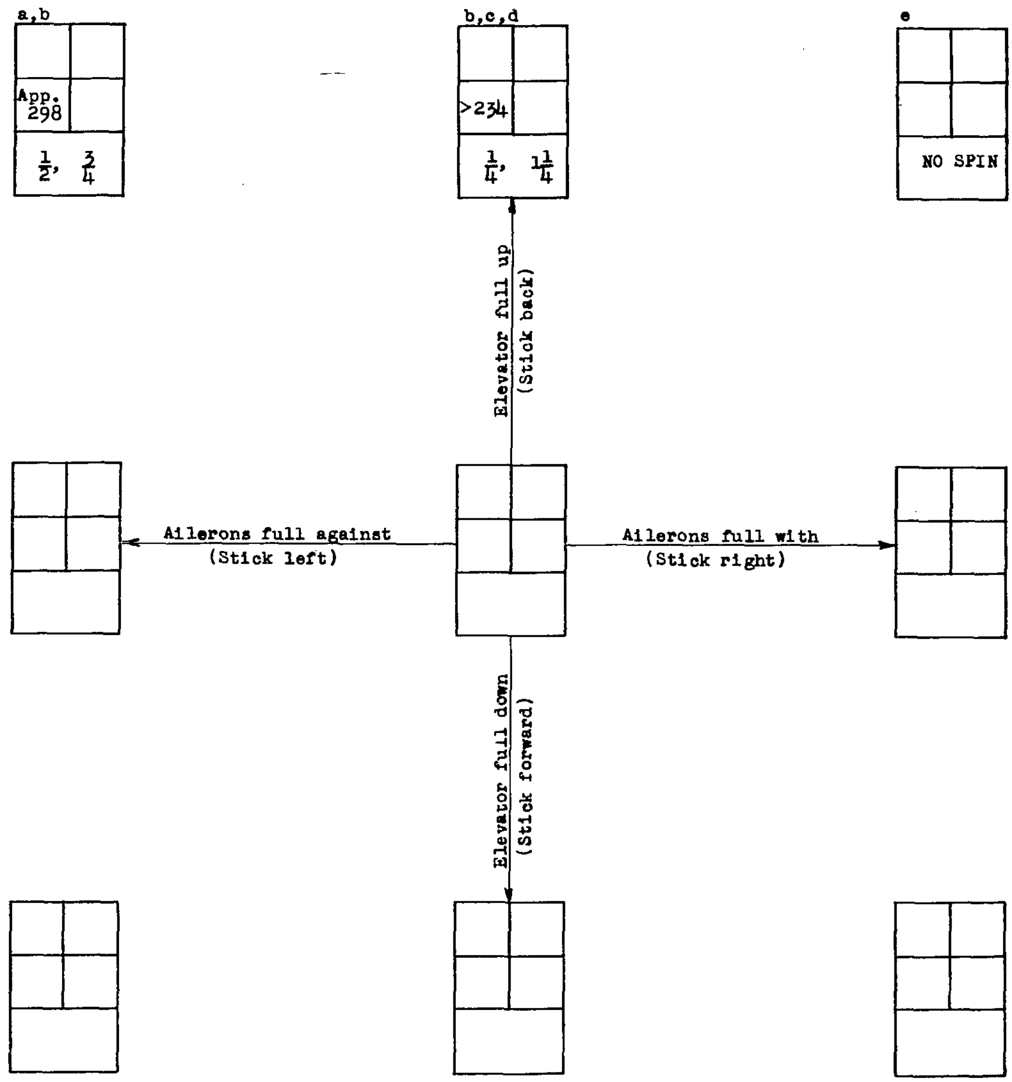


CHART 3.- SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL WITH SLATS EXTENDED FOR THE NORMAL GROSS-WEIGHT LOADING WITHOUT CENTER EXTERNAL STORE INSTALLED

[Model loading 1 in table III; horizontal-tail incidence, 4° leading edge up; recovery attempted by rapid full rudder reversal (recovery attempted from, and steady-spin data presented for, rudder-full-with spins); erect spins to pilot's right]



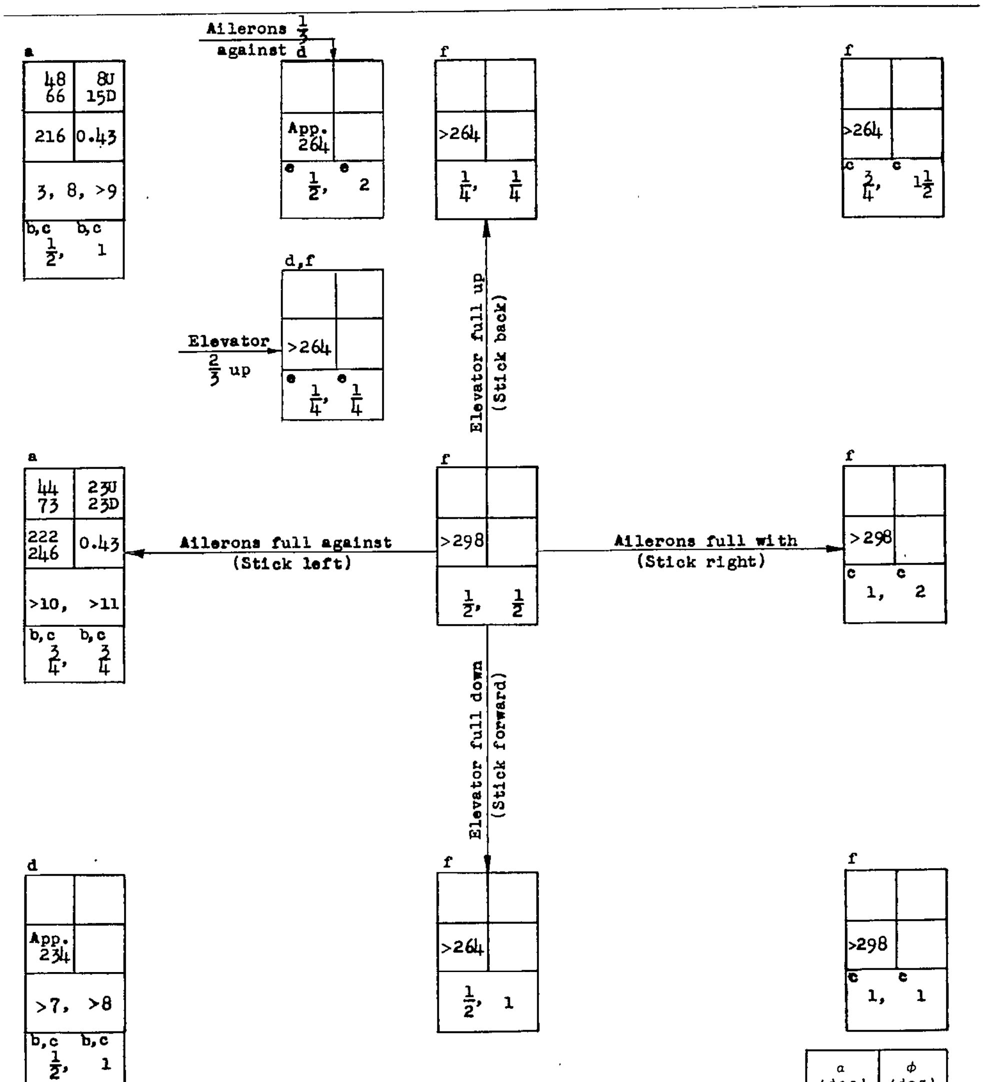
[a]Steep, wide radius spin.
[b]Steep spin; recovery attempted before final attitude.
[c]Whipping and wandering spin.
[d]No-spin condition also observed.
[e]Entered a dive, turning slightly in the direction of the aileron setting.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	φ (deg)
V (fps)	Ω (rps)
Turns for recovery	

CHART 4.- SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL WITH THE CENTER OF GRAVITY AT 17 PERCENT $\bar{c}$ WITHOUT EXTERNAL STORES

[Model loading 2 in table III; horizontal-tail incidence, 4° leading edge up; recovery attempted by rapid full rudder reversal except as indicated (recovery attempted from, and steady-spin data presented for, rudder-full-with spins); erect spins to pilot's right]



[a]Oscillatory and wandering spin.

[b]Recovery attempted by simultaneous reversal of rudder to full against the spin and movement of ailerons to full with the spin.

[c]Recovered in an aileron roll.

[d]Wandering spin.

[e]Recovery attempted by reversing rudder from full with to $\frac{2}{3}$ against the spin.

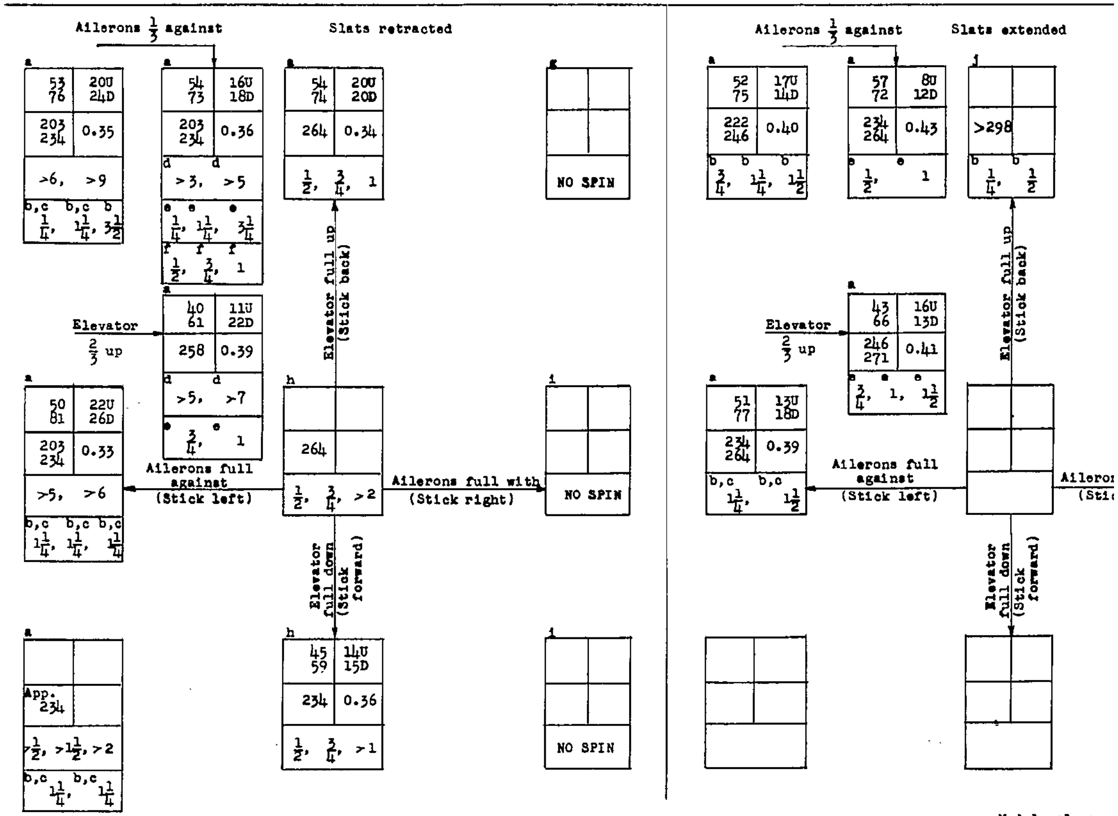
[f]Steep spin; recovery attempted before final attitude.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down
Average or range of values given.

α (deg)	ϕ (deg)
V (fps)	Ω (rps)
Turns for recovery	

CHART 5.- SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL IN THE NORMAL GROSS-WEIGHT LOADING (INCLUDES CENTER EXTERNAL STORE) WITH SLATS RETRACTED AND EXTENDED

[Model loading 5 in table III; horizontal-tail incidence, 4° leading edge up; recovery attempted by rapid full rudder rever
as indicated (recovery attempted from, and steady-spin data presented for, rudder-full-with spins); erect spins to pilo

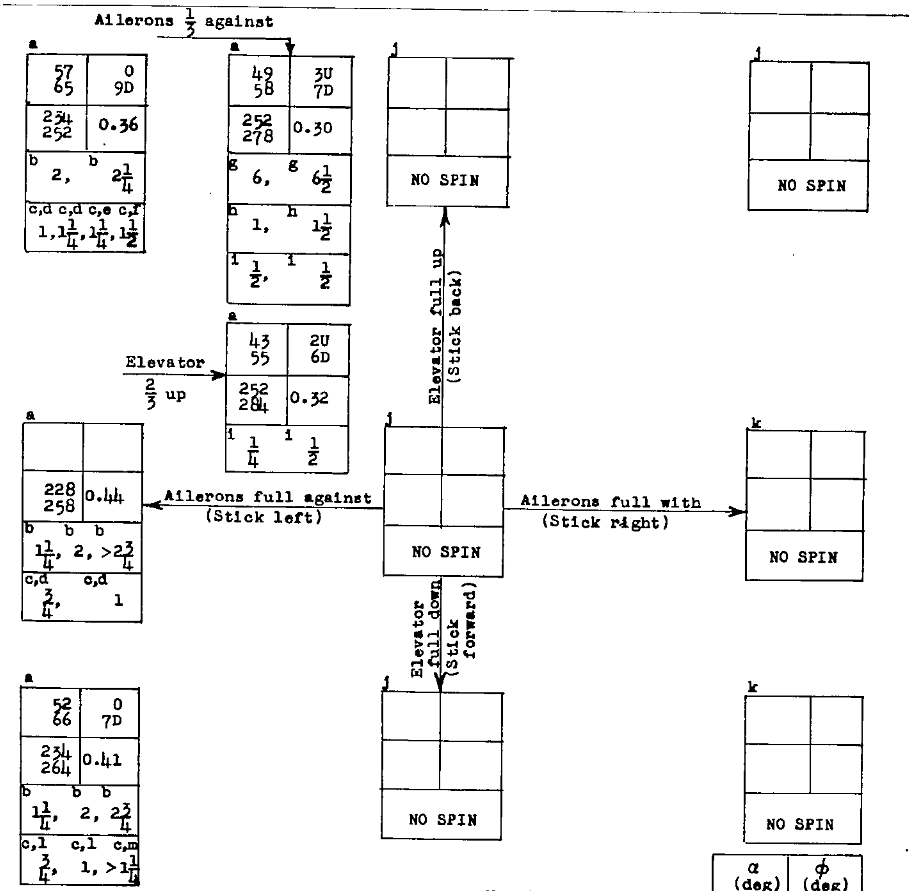


Model values converted to corresponding full-scale val
U inner wing
D inner wing
Average or ran
values give

[a] Oscillatory and wandering spin.
[b] Recovery attempted by simultaneous reversal of rudder to full against the spin and movement of ailerons to full with the spin.
[c] Recovered in an aileron roll.
[d] Recovery attempted by reversing rudder from full with to $\frac{2}{3}$ against the spin.
[e] Recovery attempted by simultaneous reversal of rudder to $\frac{2}{3}$ against the spin and movement of ailerons to $\frac{2}{3}$ with the spin.
[f] Recovery attempted by simultaneous reversal of rudder to $\frac{2}{3}$ against the spin and movement of ailerons to full with the spin.
[g] Enters steep glide, turning slightly.
[h] Whipping and wandering spin.
[i] Enters an aileron roll.
[j] Steep spin; recovery attempted before final attitude.

CHART 6.- SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL IN THE NORMAL GROSS-WEIGHT LOADING (INCLUDES CENTER EXTERNAL STORE) WITH -12° HORIZONTAL-TAIL INCIDENCE

[Model loading 5 in table III; horizontal-tail incidence, 12° leading edge down; recovery attempted as indicated (recovery attempted from, and steady-spin data presented for, rudder-full-with spins); erect spins to pilot's right]



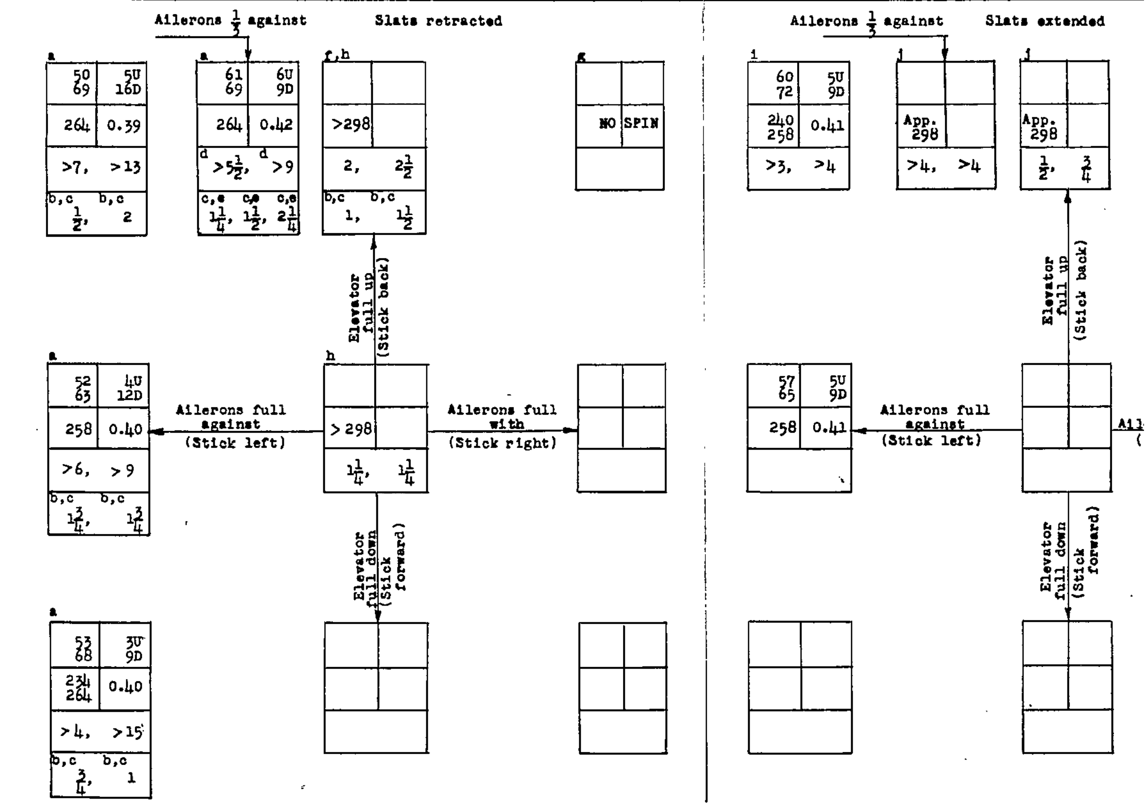
α (deg)	φ (deg)
V (fps)	Ω (rps)
Turns for recovery	

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down
Average or range of values given.

[a]Wandering and slightly oscillatory spin.
[b]Recovery attempted by simultaneous reversal of rudder to full against the spin and movement of ailerons to neutral.
[c]Recovery attempted by simultaneous reversal of rudder to full against the spin and movement of ailerons to full with the spin.
[d]Recovered in a short dive followed by an aileron roll.
[e]Recovered in a short dive followed by a turn.
[f]Recovered in a dive.
[g]Recovery attempted by reversing rudder from full with to $\frac{2}{3}$ against the spin.
[h]Recovery attempted by simultaneous reversal of rudder to $\frac{2}{3}$ against the spin and movement of ailerons to neutral.
[i]Recovery attempted by simultaneous reversal of rudder to $\frac{2}{3}$ against the spin and movement of ailerons $\frac{2}{3}$ with the spin.
[j]Entered a dive.
[k]Entered an aileron roll.
[l]Recovered in an aileron roll.
[m]Visual estimate.

CHART 7.- SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL IN THE NORMAL GROSS-WEIGHT LOADING PLUS EXTERNAL FUEL TANK STORES (INCLUDES CENTER EXTERNAL STORE) WITH SLATS RETRACTED AND EXTENDED

[Model loading 6 in table III; horizontal-tail incidence, 4° leading edge up; recovery attempted by rapid full rudder except as indicated (recovery attempted from, and steady-spin data presented for, rudder-full-with spins); erect pilot's right]

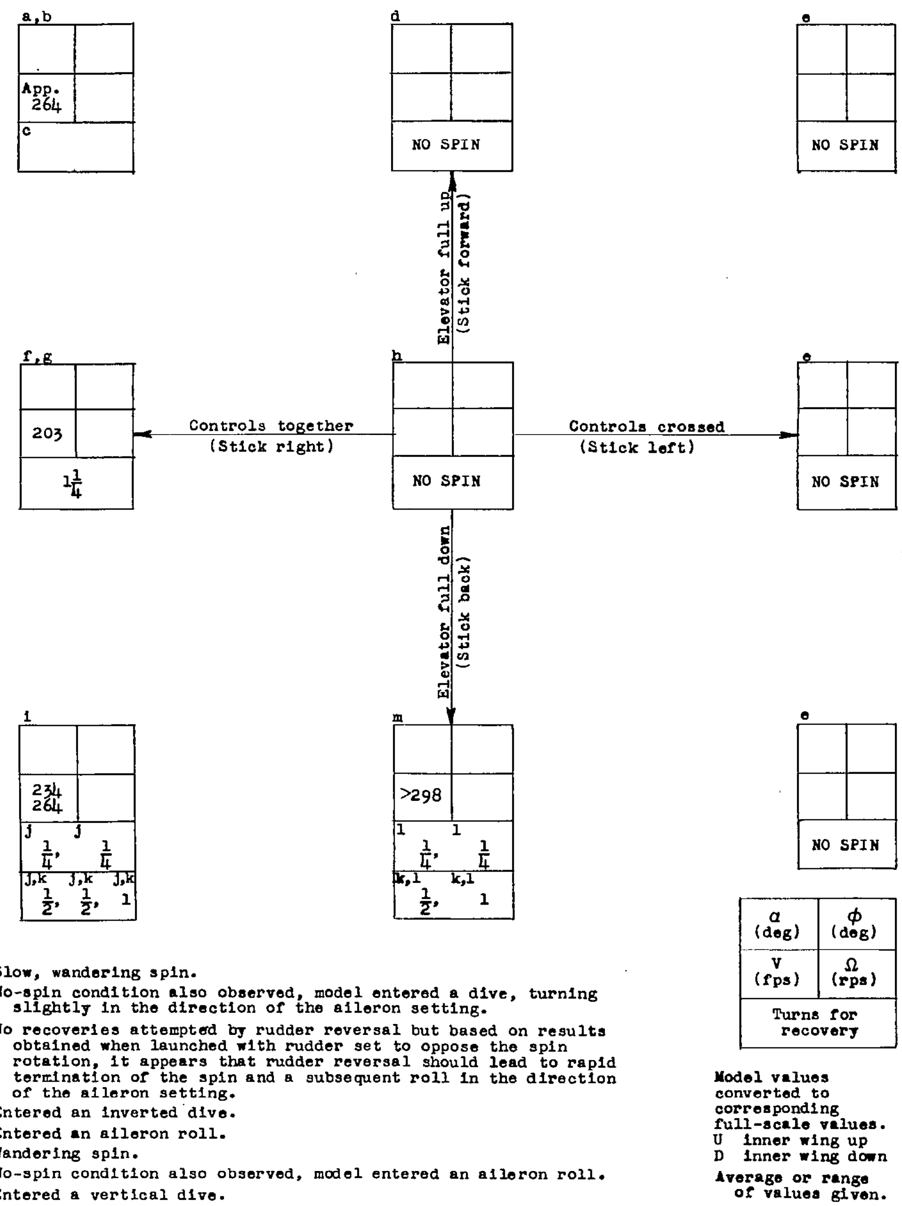


Model values converted to corresponding full-scale va
U inner wing
D inner wing
Average or ra values giv

[a]Oscillatory and wandering spin.
[b]Recovery attempted by simultaneous reversal of rudder to full against the spin and movement of ailerons to full with the spin.
[c]Recovered in an aileron roll.
[d]Recovery attempted by reversing rudder from full with to $\frac{2}{3}$ against the spin.
[e]Recovery attempted by simultaneous reversal of rudder to $\frac{2}{3}$ against the spin and movement of ailerons to $\frac{2}{3}$ with the spin.
[f]Steep slow-turning wide-radius spin.
[g]Enters a steep dive, then turns with a whip due to ailerons.
[h]Steep spin, recovery attempted before final attitude.
[i]Slightly oscillatory.
[j]Wandering spin.

CHART 8.- INVERTED SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL IN THE NORMAL GROSS-WEIGHT LOADING WITHOUT CENTER EXTERNAL STORE INSTALLED

[Model loading 1 in table III; horizontal-tail incidence, 4° leading edge up with respect to fuselage reference line when airplane is in erect attitude; recovery attempted by rapid full rudder reversal except as indicated (recovery attempted from rudder-full-with spins); spins to pilot's right]



[a]Slow, wandering spin.

[b]No-spin condition also observed, model entered a dive, turning slightly in the direction of the aileron setting.

[c]No recoveries attempted by rudder reversal but based on results obtained when launched with rudder set to oppose the spin rotation, it appears that rudder reversal should lead to rapid termination of the spin and a subsequent roll in the direction of the aileron setting.

[d]Entered an inverted dive.

[e]Entered an aileron roll.

[f]Wandering spin.

[g]No-spin condition also observed, model entered an aileron roll.

[h]Entered a vertical dive.

[i]Oscillatory, whipping, and wandering spin.

[j]Recovered in an aileron roll.

[k]Recovery attempted by rudder neutralization.

[l]Recovered in a dive.

[m]Steep spin, recovery attempted before final attitude.

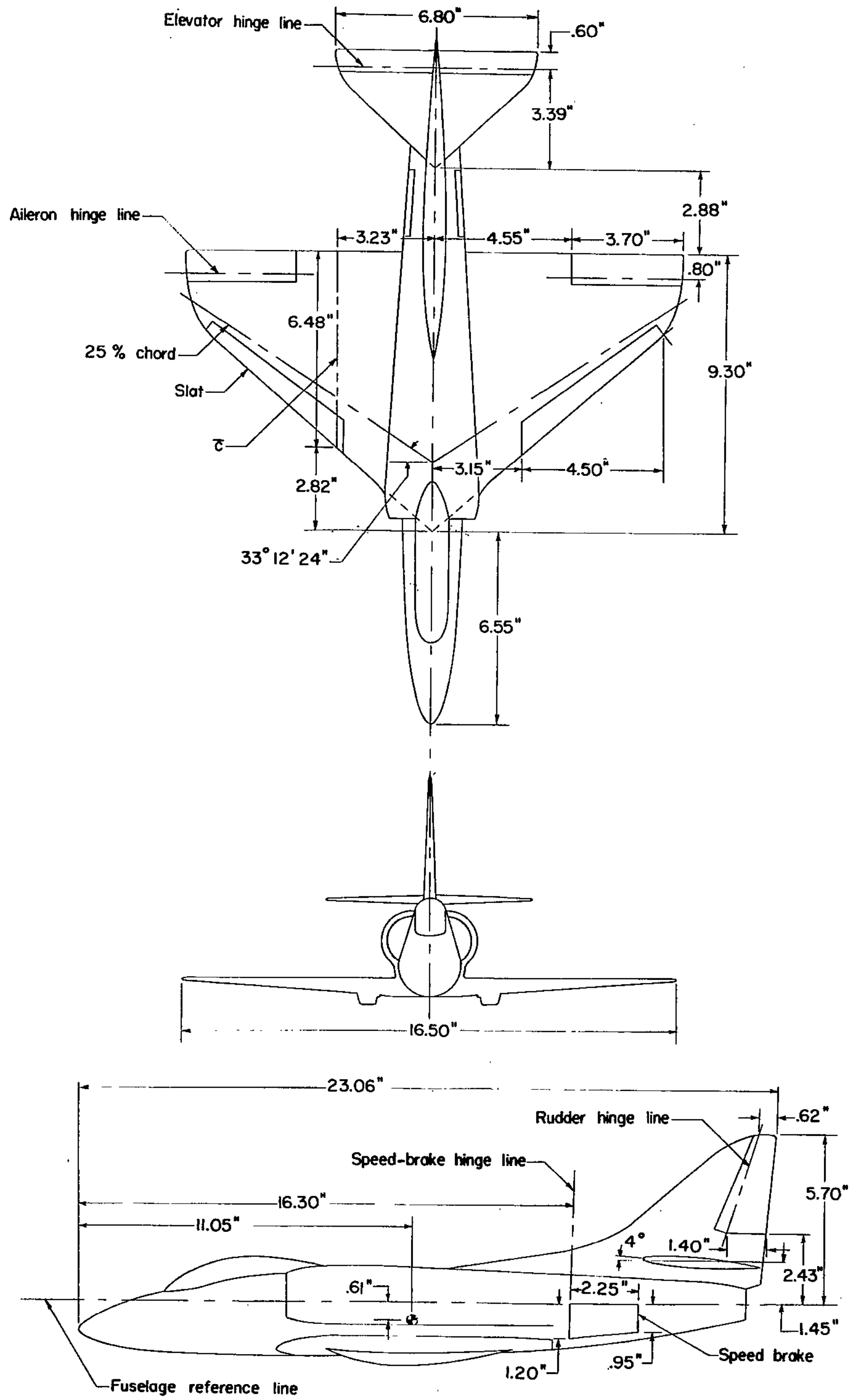


Figure 1.- Three-view drawing of the 1/20-scale model of the Douglas A4D-1 airplane. Center-of-gravity position indicated is for normal gross-weight loading with center store removed.

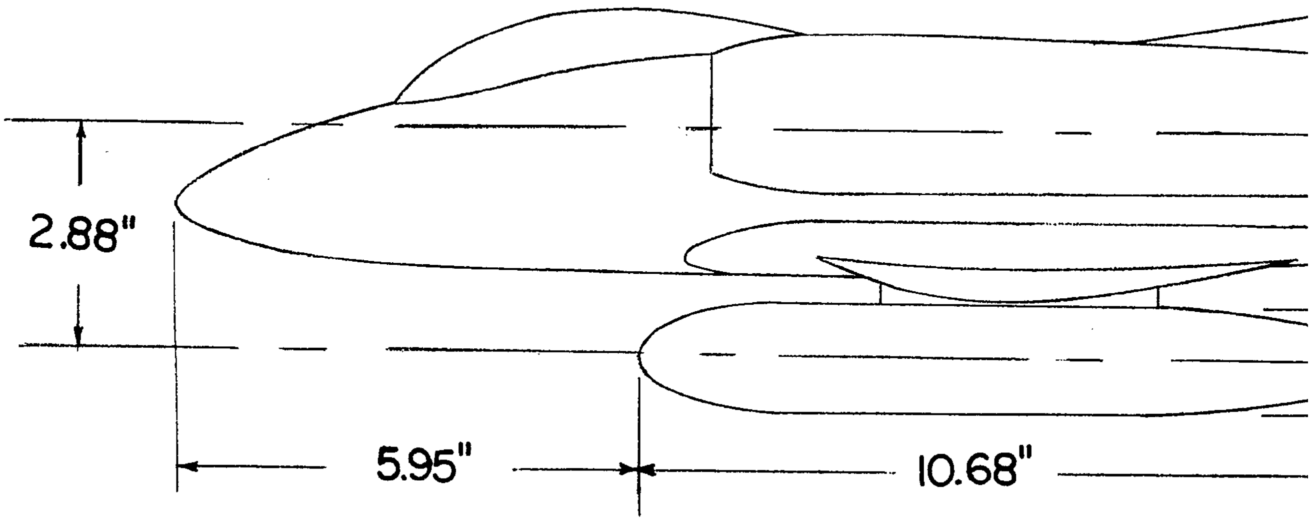


Figure 2.- Size, shape, and position of center external store invest[illegible]
on model.

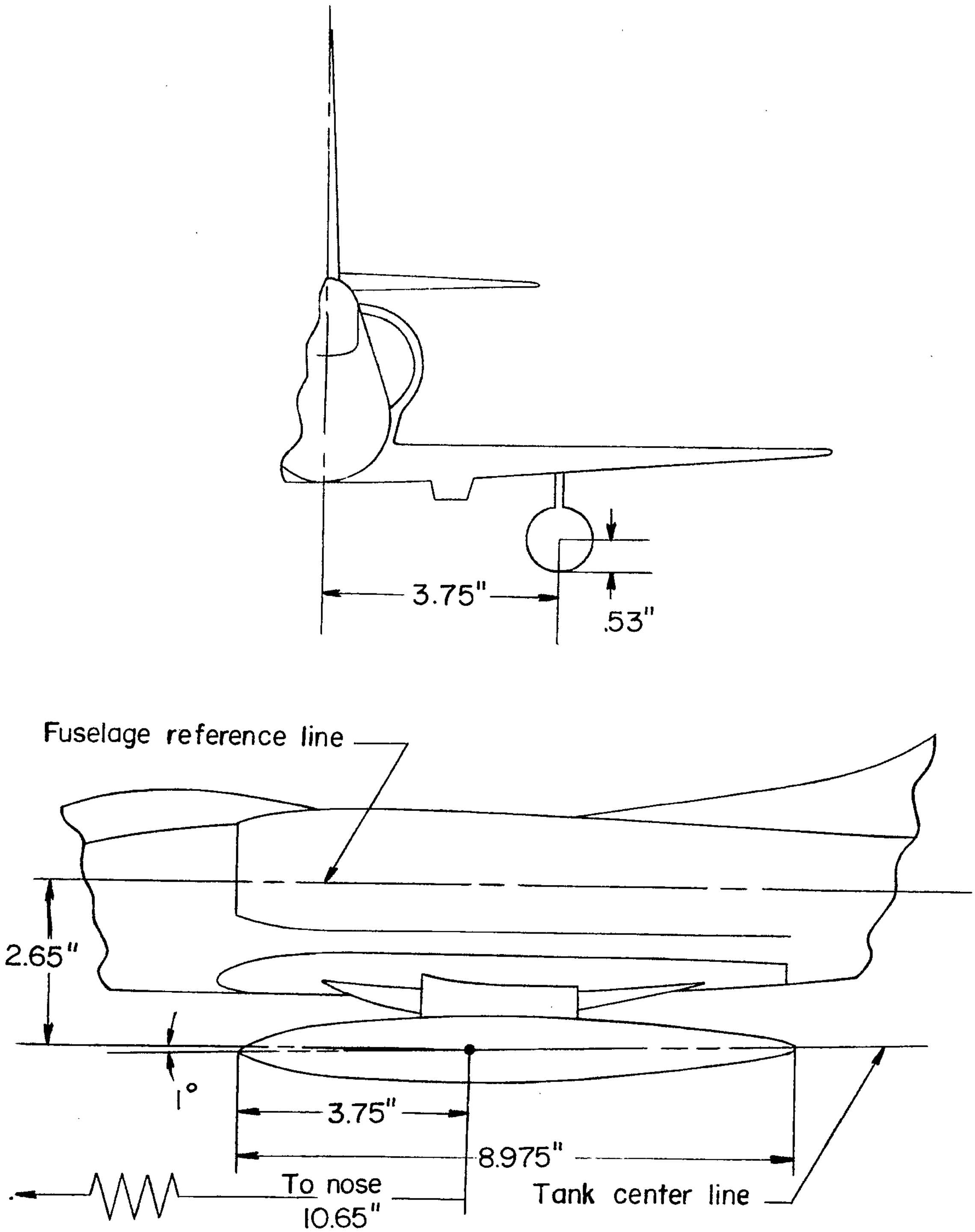


Figure 3.- Size, shape, and location of external wing fuel tanks investigated on model.

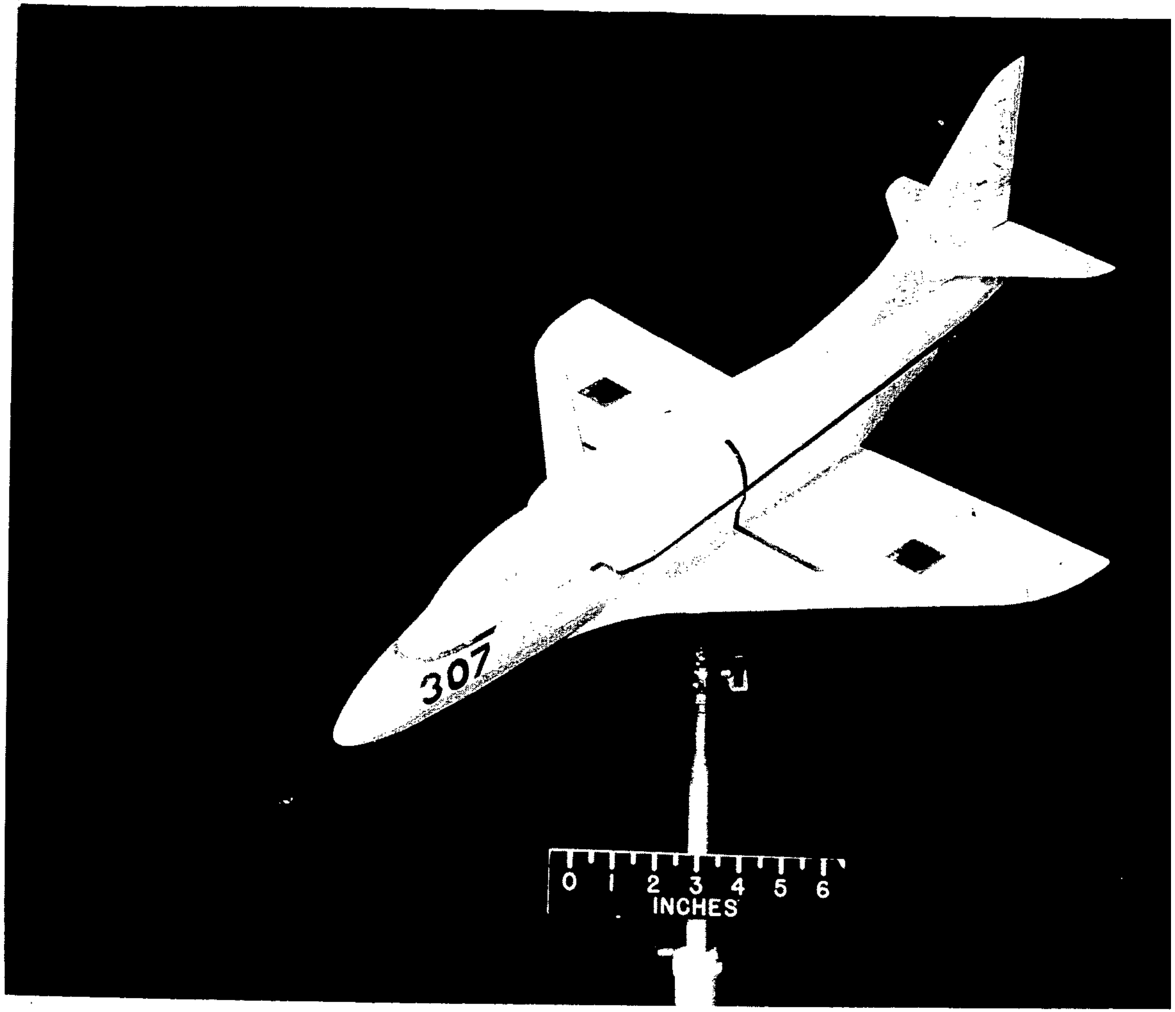


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Figure 4.- Photograph of the 1/20-scale model of the Douglas A4D-: airplane in the clean condition.

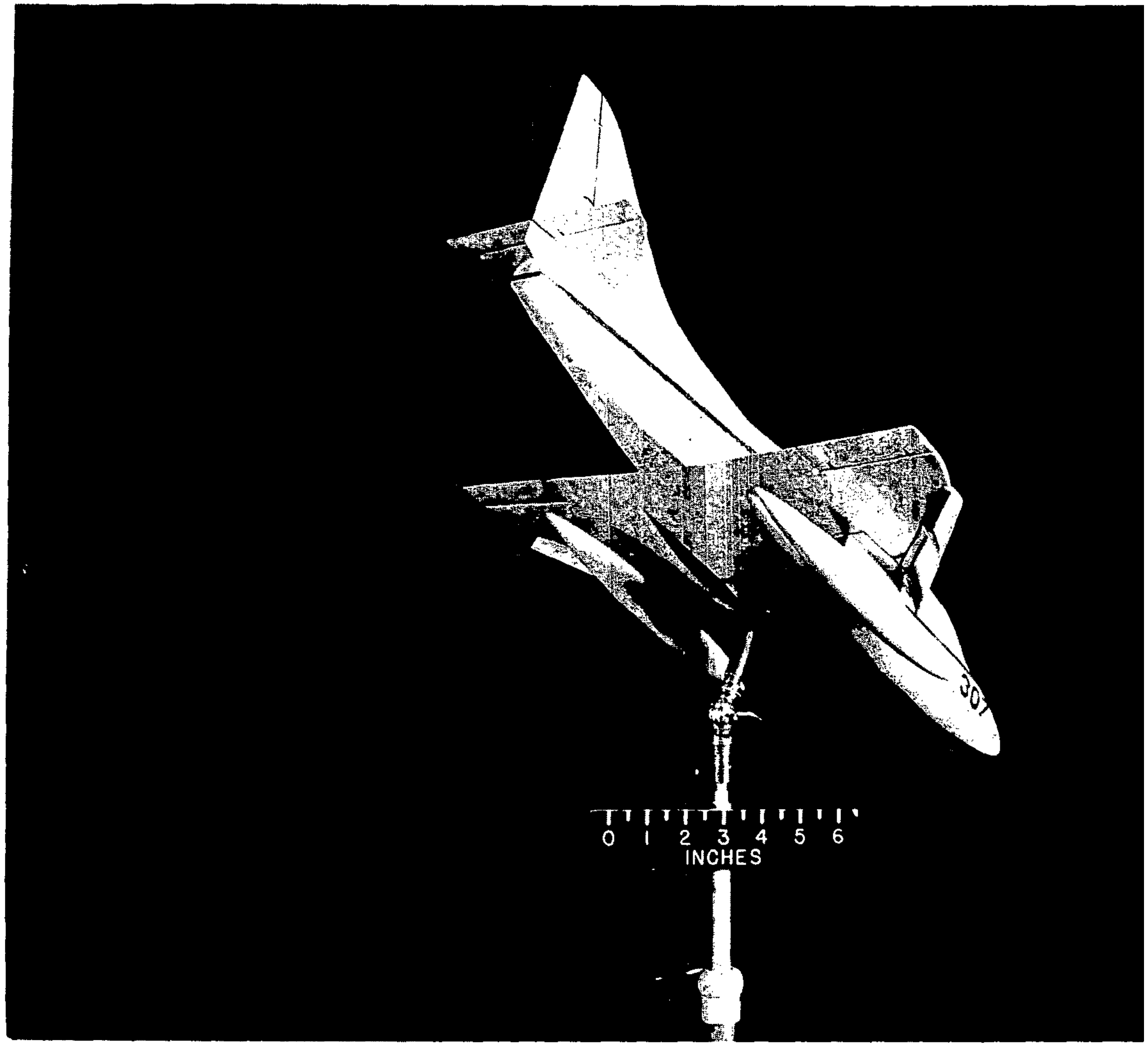

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Figure 5.- Photograph of the 1/20-scale model of the Douglas A4D-1 airplane with slats extended and external wing fuel tanks instal: